Final report

LEAP 4 Beef Automated Cutting Systems – Scott pre-production module 1 prototype

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Executive summary

Background

The goal for this project is to develop stages of automation modules for use in beef boning rooms for Australasian processors. This will be based upon previous pre-production prototypes (including but not limited to outcomes from MLA project P.PIP.0772 LEAP4Beef) and will culminate in a demonstration event to industry that seeks feedback plus expressions of interests from processors for a future staged project.

Objectives

- Multiple stage development:
  - Initially aiming to deploy a simple vision and cut path system to start with looking to find a cost-effective option that replicates human abilities.
  - Further stages are to be based on cost and benefit of more advanced sensing/mechanics vs achievable accuracy improvements.
- Robotic approach to prove core concepts required to produce a production machine.
- In plant trials to prove concepts on actual product and quantities in a production environment to prove integration and considerations for production machine.

Methodology

- A steering group was formed, involving MLA, AMPC, JBS & SCOTT, to guide project activity and act as a point of co-ordination for activity for each of the participants.
- An existing concept prototype workshop demonstration station was upgraded and redesigned where necessary for operation as a production room demonstration cell.
- Agreement was to focus on a striploin-rack-chine removal pre-production module.

The demonstration cell was installed and tested at JBS Brooklyn, during which participants gave feedback on future development paths.

Results/key findings

- Both factory and site demonstrations were well received by processor JBS.
- CNN vision analysis provided better accuracy than traditional vision analysis.

Benefits to industry

Assuming the next stage development machine can improve on a manual cut product by 1mm for 0-rib product and 2mm for 2-rib product, this would result in a yield benefit of:

- $0.722 AUD per 0-rib striploin*
- $1.444 AUD per 2-rib striploin*

Using the above assumed benefits, the value of equipment utilising a 2-year payback would equate to: $991,744 AUD**

*	This benefit is plant and commercial solution dependant.
**	There may be further costs associated with equipment installation.

Future research and recommendations

The results from stage 1 indicate less accuracy obtained than is typical from a manually cut product. Therefore, a stage 2 is proposed, to implement further sensing, enhance imitating the human operator, re-implement, train, and trial.

Objectives:

- Upgrading the sensing means on the Brooklyn stage 1 test system.
- Obtain the error from the ideal cut path data for both the manual and robotic system and report.
- Given the measured improvement versus the manual operation, propose a path to a commercial system (where initial module focuses on striploin-rack-chine removal).

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1. Background

Scott Automation and Robotics (Scott), Meat and Livestock Australia (MLA), Australian Meat Processor Corporation (AMPC) and several Australian processors have collaboratively developed a strategic beef deboning automation strategy termed LEAP4Beef.

Several pre-prototypes were developed by Scott, who was the subcontracted technology developer in a recent MDC project (P.PIP.0772) LEAP4Beef. Work completed estimated a $29/head benefit from the proposed LEAP4Beef delivering up to $10M per annum return for a high throughput beef processor. Furthermore, significant labour savings and OH&S benefits exist.

This new project between Scott, MLA and AMPC in partnership with JBS Australia will now build upon the LEAP4Beef concepts and demonstrate a pre-production prototype that focuses on a striploin chine removal. This will be demonstrated at JBS' Brooklyn facility.

The desired outcome will be to advance the technology readiness to enable a demonstration event to industry that seeks feedback plus expressions of interests from processors for a future staged project and potential host facilities.

This project represents a catalyst for MLA and AMPC to develop a clear joint plan that consolidates collective past learnings in the automated beef processing space and further allows Scott to bring their long-standing expertise.

2. Objectives

A steering committee comprising MLA, AMPC and Scott will be formed to project manage the deliverables.
Below are the key objectives for Scott to deliver:

- Bringing together the outcomes from the LEAP4Beef system development project with the prior Scott and MLA work on the first module to install and demonstrate the first LEAP4Beef module.
- The first module will implement the Striploin deboning (chine removal) technology as a manually loaded module with simple sensing.
- Implementation will be structured to accommodate a multistage programme of work devised to allow a full LEAP4Beef system to be implemented with advanced sensing in a staged / stepped approach in a series of future projects.
- This pre-production prototype will be demonstrated for industry participants at JBS Brooklyn.

2.1 Scope for steering committee terms of reference

From this project it is anticipated that a new product will emerge in a prototype form. Scott in collaboration with MLA, AMPC and JBS will be well placed to then progress this to a commercial product as a next/later stage. Given there are several active participants in this project including MLA, AMPC, JBS and Scott this Milestone is designed to form a steering group to guide project activity and act as a point of co-ordination for activity for each of the participants. It is anticipated that the steering group will keep the project on track and focused on achieving outcomes that are desired for industry.

It is anticipated that Scott will require guidance from JBS as the host site for the prototype to ensure the system integrates with the Brooklyn facility, processes to the correct specification, is suitable for the production room situation.
It is anticipated that Scott will require guidance from MLA and AMPC to ensure that industry objectives are represented and used as a guide to any decision points that arise during the project.
With representation by the industry peak bodies as well as direct processor representation the project will have the guidance required to ensure that both the immediate outputs of this project are fit for purpose as well as the strategic goals of the industry are being considered in the project objectives.

3. Methodology

3.1 Steering committee

A steering group was formed to guide project activity and act as a point of co-ordination for activity for each of the participants.

Terms of reference were circulated to JBS, Scott, MLA and AMPC that outlines key functions and principals the steering group will operate to.

3.2 Design and upgrade concept prototype

The activities to upgrade the concept prototype workshop demonstration station to become a production room demonstration cell included:

- Agreement on proposed footprint and location within JBS Brooklyn production room.
- Consider which components of the concept prototype workshop demonstration station required upgrading for operation as production room demonstration cell.
    - Which components can be galvanised?
    - Which components will need to be remanufactured/purchased in stainless steel?
    - What additional components will be required for hygiene and washdown environment?
- Identify all long lead items and order.
- Research Australian product sizes to design and build suitable sized product clamps.
- Analysis of previously CT scanned NZ product to determine minimum clamping range and chine cut capability.
- Scope vision system design and camera selection.
- Testing vision system on product within New Zealand production room.

- Electrical design and build.
- Guarding and safety system design and build, including modes of operation/gate entry.
- Re-write of robot code for operation via pushbutton HMI, including new home, washdown/service positions, and recovery sequence.

3.3 Demonstrate viability prior to shipping.

To demonstrate the operability and capability of the production room demonstration cell at the Scott Dunedin factory, the following testing method was conducted:

1. Short loins of varying size, orientation and grade will be manually loaded into the clamps. Product is clamped via pneumatic actuation. A valve solenoid is switched to clamp via a manually actuated electrical switch installed on the side of the pneumatic cabinet.
2. The following information will be recorded prior to loading:
    a. The test number: #1, #2, #3…
    b. The product grades.
    c. The product size with reference to the rib count: “0-Rib”, “1-Rib”, “2-Rib” or “3-Rib”.
    d. The weight of the product prior to cutting.
    e. From which end of the animal will the cut begin: Head (Cranial) or Tail (Caudal).
3. A video of the cut will be recorded, with the recording starting after loading the product.
4. By pressing the start button, the following will be initiated:
   The image capture, vision analysis and communication of cutting co-ordinates to the robot controller. The bandsaw will also begin to run-up to cutting speed.
5. Before the robot moves to start cut position, the stop button shall be pressed, pausing the auto-sequence to allow for human analysis and confirmation of the vision system generated co-ordinates. If the cutting ordinates are deemed to be within what would be expected, the start button will be pressed to continue the auto-sequence and cut the product.
6. After cutting the product the video recording shall stop and photos of the cut product still clamped will be taken to identify the cut path and to note if there was any significant movement of the striploin which will become unclamped as the bandsaw progresses through the cut path. Photos of both sides of the cut plane will be taken and stored.
7. The weight of the chine bone, with potential yield loss still attached, shall be recorded.
8. On the striploin, starting with the button bone at the cranial end of the product (Button #1, Button #2…), each button will be assessed and recorded as split. The following categories will be used to determine the split success (Split?):
    a. Y – Yes
    b. PB – Partially, can be broken with finger pressure.
    c. PBH – Partially, can be broken with a hammer.
    d. N – No, button bone remains bridged and cannot be split with a hammer.
    e. M – Missed, cut was above the button bone.
9. On the chine bone, starting with the button bone at the cranial end of the product (Button #1, Button #2…), each split button and partially split button with have the depth of the valleys adjacent to the button measured and recorded. Each valley will be identified as Dorsal or Ventral.
   The measurement will be taken using a 6in steel rule, plunged into the valley and recording the distance from the bottom of the valley to the cut plane.
10. The chine bone will then be fleeced of all tissue, as much as practically possible. It will then have its weight recorded to give an indication of the potential yield left on the chine bone.

3.4 Ship, install and setup for demonstration.

- Ship
    - The method includes cleaning, packing, and shipping activities.

- Install
    - The method includes.
        - JBS site integration activities.
        - Scott machine installation activities.

- Setup for demonstrations.
    - The method includes validation of safety functions, setup & calibration.

3.5 Testing and demonstration in plant

The activities to achieve milestone 5 included:

- Install and commission the robot cell in the JBS Brooklyn beef boning room.
- Commission the vision system using traditional vision analysis.
- Measure and classify button splitting success for both manually and robotically cut product to confirm how close the stage 1 system is to the manual process.
    - Products will be categorised by the number of ribs a short loin contains.
    - On the striploin, starting with the button bone at the cranial end of the product (Button #1, Button #2…), each button will be assessed and recorded as split. The following categories will be used to determine the split success (Split?):
        - M – Missed, cut was above the button bone.
        - Y – Yes
        - PB – Partially. Either one or both bridges can be broken with finger pressure.
        - PBH – Partially. Either one or both bridges can be broken with a hammer.
        - N – No, button bone remains bridged and cannot be split with a hammer.
    - On the chine bone, starting with the button bone at the cranial end of the product (Button #1, Button #2…), each split button, partially split button, and non-split button will have the depth of the valleys adjacent to the button measured and recorded. Each valley will be identified as Dorsal or Ventral.
      The measurement will be taken using a 6in steel rule, plunged into the valley and recording the distance from the bottom of the valley to the cut plane. This measurement equates to the cut error from the ideal cut plane for each button bone. Non-split buttons, where the bridges between the articular process (button) and the lateral and traverse processes will be measured where possible without damaging the saleable striploin product or otherwise estimated based on the width of the bridge.
- Implement a convolutional neural network (CNN), or machine learning model, to test for improved accuracy of vision analysis.

- Analyse recorded button valley depths to ascertain mean cut accuracy values and average standard deviations.
- Invite representative from MLA, AMPC and JBS plants to a demonstration event, that will include a review of where the Beef Automation project is to date and to seek buy in for future development paths.
- With input from the steering committee, set what are acceptable and unacceptable results regarding button split classification.
- Establish potential benefit model.
- Recommend potential next steps – Stage 2.

NOTE: The robot bandsaw will cut in a straight line, to and from points on the cranial and caudal cut faces of the short loin. Each product will have its bespoke points and cut path calculated by the vision system prior to the robot bandsaw moving toward the product to cut.

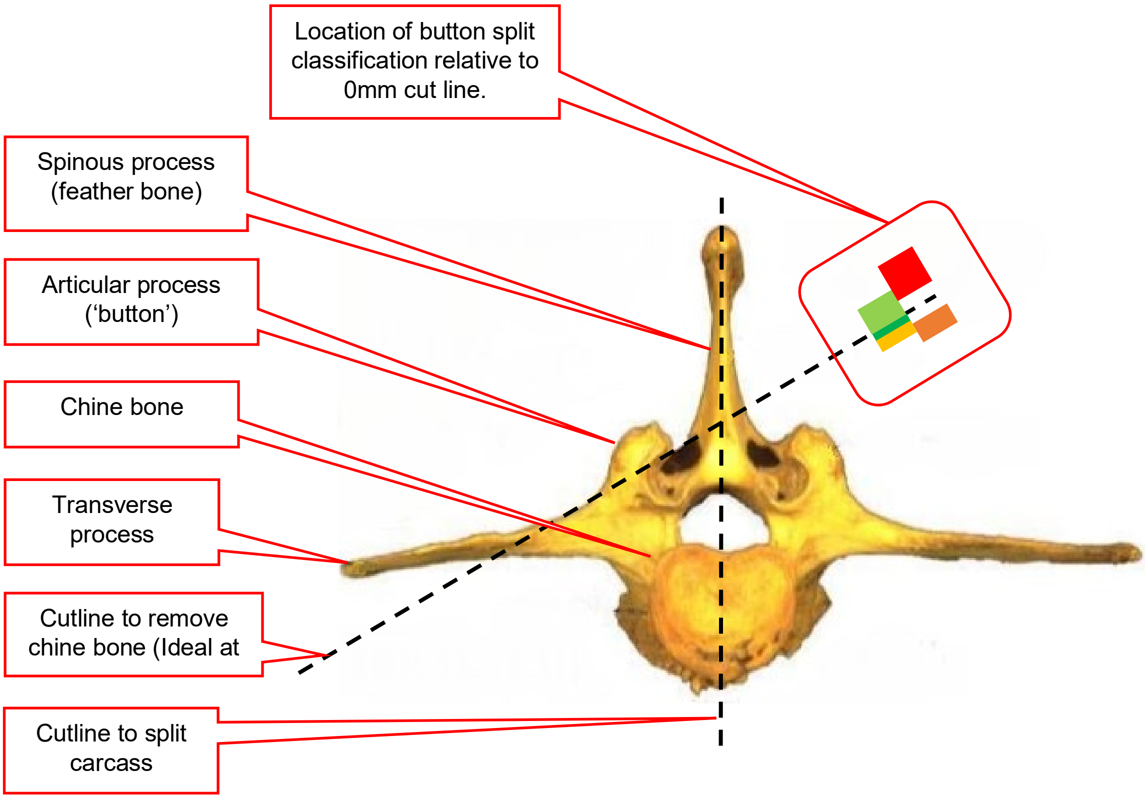

Figure 1 – Chine bone with button splitting classification highlighted.

Button split?	Description	Min. (approx.)	Max. (approx.)	Yield
M	Missed – Button bone is not visible on the chine bone side of the bandsaw cut. There may be a streak of that connective tissue showing on the striploin side of the cut, but no bone so the blade has missed the button.	+10mm	+32mm	Lost, with not ability to recover as first cut is within eye meat.
Y	Yes – The button is clearly separated from the surrounding chine bone, feather bone and transverse process. Fatty, white connective tissue connecting the bones on the striploin side of the cut, whilst a very slight bridge showing on the chine side of the cut would typically indicate a 0mm measurement.	0mm	+18mm	Good to fair. Possible room for improvement.
PB	Partially broken – One side of the button may be separated, but the other side is still “bridged”, but pressing on the connecting bridge with solid finger pressure will snap it. Typically, this type of bridge will indicate a -1mm or -2mm measurement.	-3mm	0mm	Maximum yield while button remains relatively easy to remove.
PBH	Partially broken (hammer) - One side of the button may be separated, but the other side is still “bridged”, but pressing on the connecting bridge with solid finger pressure will not snap it. A good solid swing of the button hammer will break the bridge. Typically, this type of bridge will indicate a measurement between -3mm and -10mm.	-10mm	-3mm	Maximum yield, but buttons are difficult to remove and will require additional work. Could lead to lower throughput.
N	No – One or neither side of the button may be separated. Both or one side is still “bridged”, but the hammer will not snap it.	-15mm	-5mm	Strip loin will need another cut, which may lead to further yield loss as the product no longer has the chine bone for rigidity.

Figure 2 – Button splitting classification definitions. Also see Figure 2.

SCOTT

364 Site Test Results

Record all known product information. Record product weight before cutting, chine weight, fleece chine bone of all saleable meat & record weight again					DATE:	JBS Brooklyn
Short Loin ID	Grade	Size	Weight	Cut from end? (record which end of product is the start of the robot cut path)	Weight of Chine	Weight of Chine (saleable meat removed)
EXAMPLE	Bull	"1-Rib"	7.925kg	TAIL	1.565kg	1.365kg
#1						
#2						
#3						
#4						
#5						
#6						
#7						
#8						
#9						
#10						
#11						
#12						
#13						
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#25						
#26						
#27						
#28						

Figure 3 – Example of data collection form 1.

SCOTT

364 Site Test Results

Measure depth from dorsal and ventral tangent points (bottom of "valley" between the button bone and spinous or transer processes) to cut surface plane | DATE: | JBS Brooklyn

Short Loin ID	Button #1 (at head end)			Button #2			Button #3			Button #4			Button #5			Button #6			Button #7			Button #8			Button #9			Button #10		
	Split?	Dorsal Depth	Ventral Depth	Split?	Dorsal Depth	Ventral Depth	Split?	Dorsal Depth	Ventral Depth	Split?	Dorsal Depth	Ventral Depth	Split?	Dorsal Depth	Ventral Depth	Split?	Dorsal Depth	Ventral Depth	Split?	Dorsal Depth	Ventral Depth	Split?	Dorsal Depth	Ventral Depth	Split?	Dorsal Depth	Ventral Depth	Split?	Dorsal Depth	Ventral Depth
EXAMPLE	Y	5mm	3mm	Y	6mm	4mm	PB	2mm	0mm	PBH	-	-	PBH	-	-	PBH	-	-	PB	0mm	0mm									
#1																														
#2																														
#3																														
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Figure 4 – Example of data collection form 2.

4. Results

4.1 Room layout

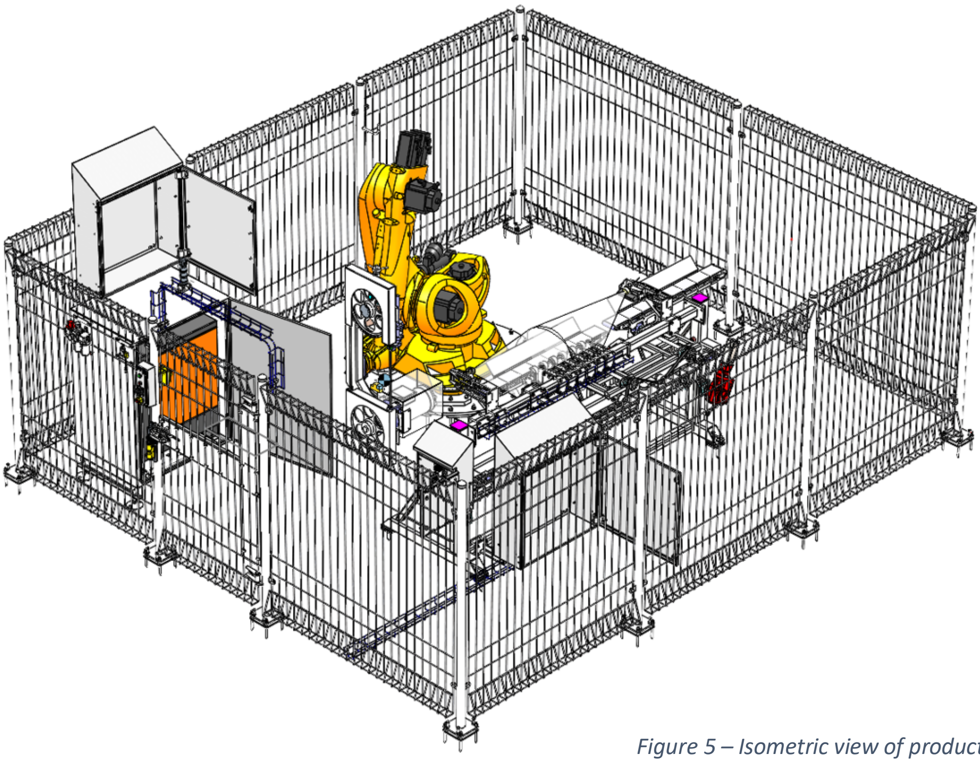

Figure 5 – Isometric view of production cell.

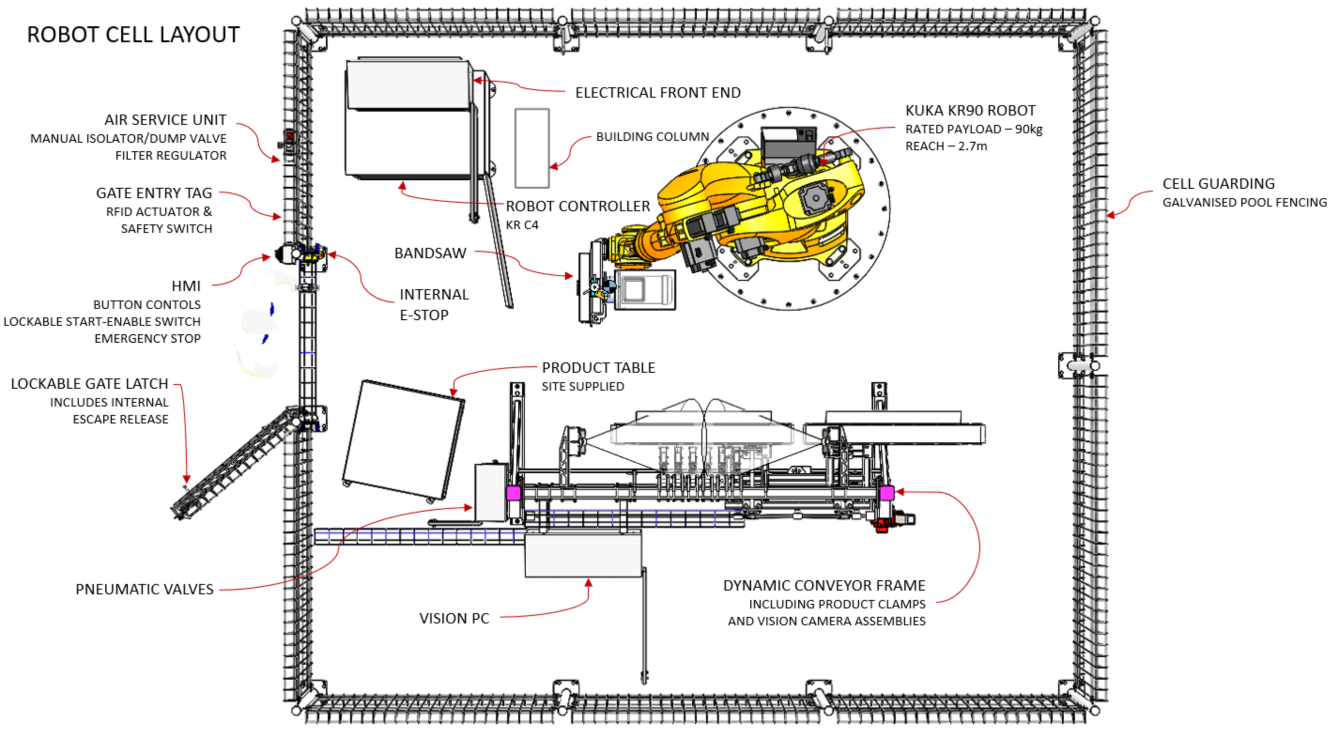

Figure 6 – Plan view of production cell.

4.2 Mechanical design & build

4.2.1 Robot

A Scott owned Kuka KR90 R2700 robot from the prototype cell has been loaned to this project. A protective bag covering for a similar sized robot was purchased from Scott Service department. The bag has been fitted and robot movement checked to confirm bag does not rip when moving through defined auto sequence paths.

The robot foot and base plates were re-manufactured in stainless steel for use in a production room.

4.2.2 Bandsaw

A previously designed and built robot mount-able bandsaw from the prototype cell has been loaned to this project. The bandsaw was stripped, accessed for operability, and upgraded as necessary. Upgrades included:

- Frame – paint removed, and zinc plated.
- New stainless steel shaft bearings.
- New blade guides and holders manufactured.
- Stainless steel motor cover for hygiene.

4.2.3 Dynamic conveyor

An existing conveyor frame for use with a robot mounted bandsaw was re-used for this project. The conveyor frame was stripped and upgraded as necessary. Upgrades included:

- Frame – Hot dipped galvanised.
- New shaft bearing – Stainless steel with food grade suitable plastic housings.
- New roller bearing – Stainless steel.
- New drive belt pulleys - Stainless steel.
- New toothed drive belts, including spare.
- New conveyor belt, old belt cleaned up and available as spare.
- Various mild steel components remanufactured as stainless steel.

4.2.4 Vision

Cameras have been purchased for this project. Camera mounting brackets were manufactured in stainless steel to fix the cameras to the dynamic conveyor frame. Position adjustability has been included in the design, but this is not expected to be used once optimal positions and locations have been found.

The vision PC is required to be located close to the cameras to reduce the cable runs between camera and PC. The Vision PC has been housed inside a stainless-steel hygiene enclosure which is mounted to the dynamic conveyor frame using fabricated stainless-steel brackets.

4.2.5 Clamps

Initially precedent clamp design from the recent MDC project (P.PIP.0772) LEAP4Beef was utilised and manufactured. However, whilst analysing the 41 New Zealand product CT scans and the 100 Australian beef side scans, it was realised that these clamps would not be suitable to allow appropriate clearance to cut the smallest of the demonstrable range.

4.2.6 Pneumatics

A pneumatic air service unit consisting of a manual isolation and dump valve, filter, regulator, and micro mist separator is mounted to a plate which is attached to the exterior of the guarding, near the access gate.

All pneumatic valves, required to operate the clamps, are located within a small stainless-steel hygiene enclosure that is attached to the dynamic conveyor frame.

4.2.7 Operator HMI

In accordance with the scope of work, a simple pushbutton human machine interface has been designed and built. It features:

- Start button. Single press to initiate robot auto-sequence. Hold to run for recovery sequence.
- Stop button. Stops the robot auto-sequence while keeping the bandsaw running to visually check the start cut position from outside of the guarding.
- Start-up enable switch. This is lockable with padlock(s) and hasp(s) for multiple people entering the cell.
- Emergency Stop
- Robot mode selection switch
    - Auto-sequence
    - Recovery sequence
    - Maintenance/Cleaning position

- Reset button to reset the safety system after gate entry, emergency stop or fault.

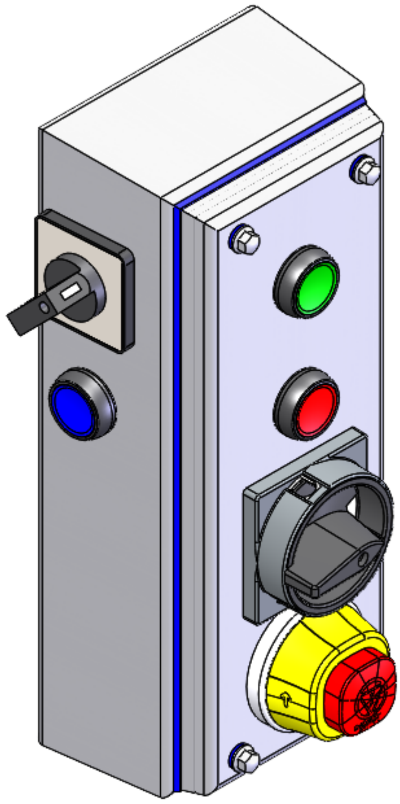

Figure 7 – Operator HMI

4.3 Safety

A machine risk assessment (MRA) was undertaken, and it was identified that interlocking guarding would be required as a means of risk mitigation for personnel entering the cell while the robot and bandsaw are enabled and active.

4.3.1 Guarding

Guarding has been designed to utilise galvanised pool fencing panels. The footprint of the layout is largely driven by the panel aperture size and minimum safe reach through distance to hazards.

Stainless steel guard posts have been fabricated.

4.3.2 Gate entry

During steering committee meetings, safety and operability were regularly discussed and it was deemed a detriment to operability to have personnel wait for up to one minute for the bandsaw to cease moving (wheels rotating) before unlocking the gate to allow access. Contrary to the scope of work, it was accepted that the addition of a braking resistor for the bandsaw motor drive would improve the operability of the cell by reducing the bandsaw run-down time to <10 seconds.

There are two methods of gate entry, depending on the task to be performed.

Method #1 – Multiple personnel entering cell.

This method is considered the main method for cell entry and is to be followed for longer durations such as maintenance or cleaning activities.
Before entering the gate, the start-up enable switch must be switched to the OFF position and LOTO procedures followed. Use a hasp for >1 people.
The robot and bandsaw cannot be enabled unless the start-up enable switch is in the ON position.

Method #2 – Single operator gate entry for the purposes of loading and unloading product.
This method is intended for more frequent and shorter durations, where the likelihood of following LOTO procedures may be seen as detrimental to operability.
Before entering the gate, the operator removes the GATE ENTRY TAG from the receptacle mounted on the guarding exterior, near the access gate. They must keep the tag on their person while inside the cell. The robot and bandsaw cannot be enabled unless the gate entry tag is sensed in its receptacle.

4.4 Electrical design and build

The robot controller is required to be close to the robot, within the production room. A custom-made stainless-steel enclosure for the robot controller has been purchased and loaned for this project.

All power distribution, motor drive and safety controller reside in a stainless-steel hygiene enclosure.

Reticulation combines the HV, LV and air services in the same truncation. Truncation in several places is stainless-steel cable basket which services are cable tied too. The galvanised pool fence panels may also be used to cable tie services.

All services have been designed ‘plug and play’ to allow for easy installation without an electrician required to re-terminate on site.

4.5 Vision system development and training

A basic vision test rig was constructed and taken to Silver Fern Farms Finegand site for the purposes of capturing images of short loins prior to chine removal, and of the removed chine bones. This was to find and measure external target markers that could be used to reliably identify the chine bone cut position.

This captured data was also utilised to create and train a convolutional neural network (CNN) to determine cut position.

Results of CNN cut offset from manual results (at ends)
Mean offset: -0.6mm
Standard deviation: 2.9mm

Limitations:

- The "valleys" adjacent to the button bones are not visible.
- The robot cannot "feel" through the cut compared to an operator.
- An operator can make a second cut to remedy the product before it continues along the production line. The CNN data set is from manual process and therefore will include first cut operator error.
- The robot will cut straight, point to point, with no adaptation along the length of cut.

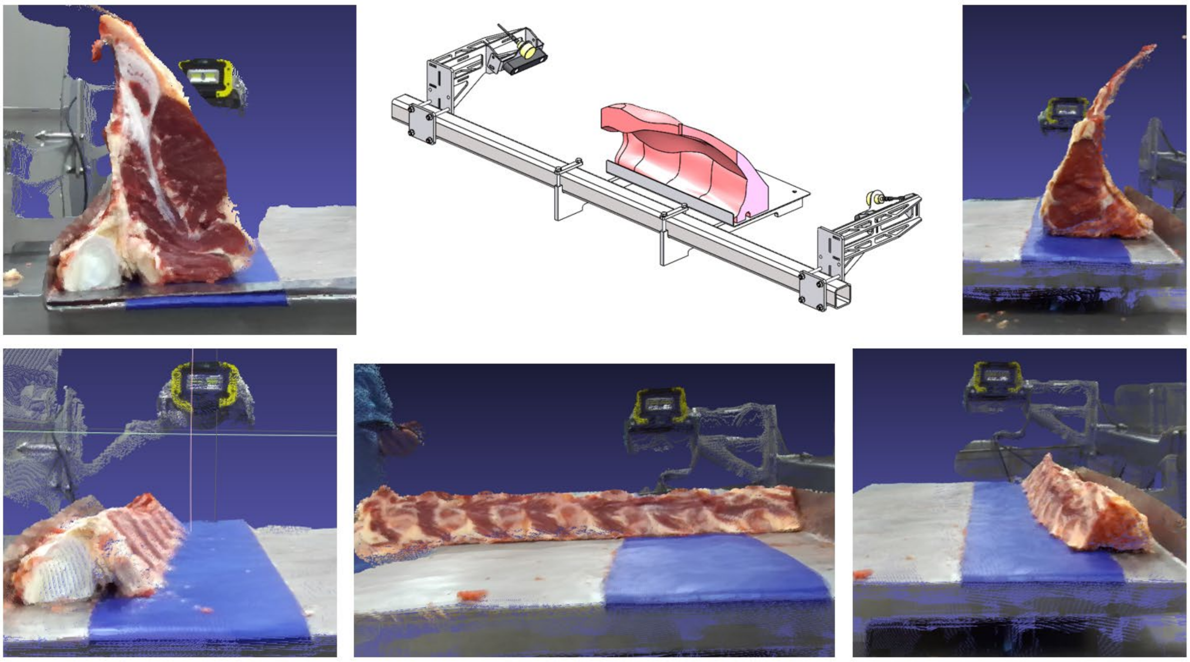

Figure 8: Vision Test rig and vision capture

The CNN model predicts the cut line. The prediction is marked blue, and is the location a bandsaw operator would aim to cut is marked green.

Figure 9 – Example of CNN predicted cut.

4.5.1 Traditional vision analysis

The geometric position is determined with the camera such that the image can be scaled for input to the vision analysis.

Because the analysis relies on heavily on the colour of different parts of the image, it becomes more difficult to distinguish between the product and the conveyor or clamps if they are covered in meat from previous cuts. Other issues may occur such as the lens being obscured by either moisture or bandsaw sawdust. For this reason, we progressed to a CNN strategy.

4.5.2 Convolutional neural network approach

A convolutional neural network (CNN) is a computational approach that involves providing a database of inputs and outputs. The model architecture performs many calculations on the input data to produce an output. When training a CNN, the model is then evaluated on how close the output is to the expected output from the database, and the calculations are adjusted based on close those outputs are.

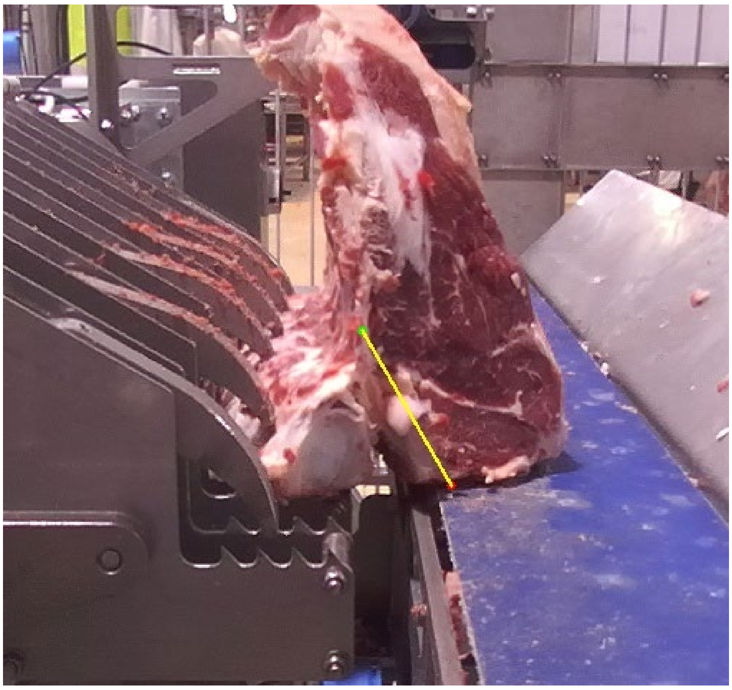

Figure 10 – The two-point output from a CNN and the line drawn between them, indicating the cutting line.

For this problem, we used manually marked data as shown in Figure 10. This involved drawing two points to define a cut line. This is then used to train the CNN. Ideally in future testing, there will be feedback after product is cut to generate more accurate data for training.

This approach is more reliable in this situation because it relies more directly on the features within the image and will automatically account for the variation in product and conditions given data in the database to train on.

However, this approach has two disadvantages:

1. The calculations performed by a CNN are very opaque. Using the traditional approach, the process is divided into granular steps. This means if the output of the analysis is incorrect, the individual steps can be analysed to see clearly what caused the problem. For a CNN, there is no intermediate steps for its part. This makes it difficult to understand what causes a problem and limits the ability to address them directly.

2. A CNN can only be trained once there are many examples of input and output for the problem. The number of examples needed will depend on the complexity of the problem

involved, and the required accuracy. For example, a prior SCOTT development program for marking ribs on x-ray images used around 3000 examples to achieve 99% accuracy.

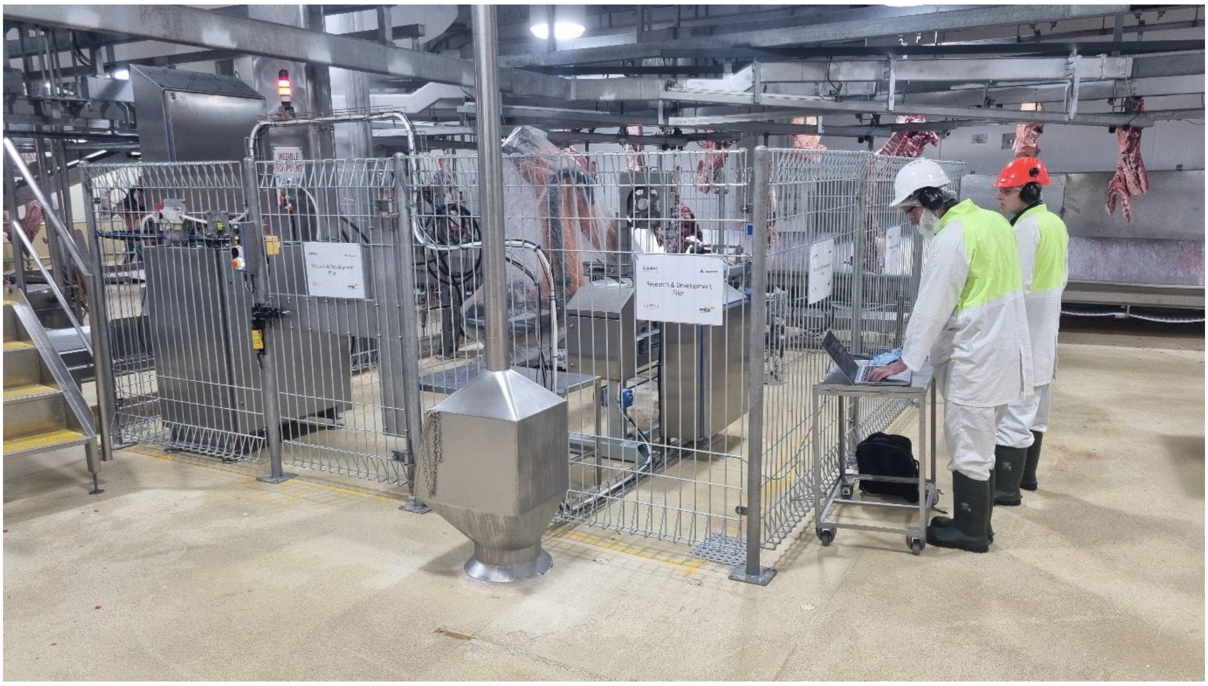

Figure 11 – Commissioning vision system on site at JBS Brooklyn.

Figure 12 – Results and measurements being recorded.

4.6 Factory demonstration of viability

14 short loins were tested, and relevant metrics were recorded. Photos and video of the set up and test were also recorded. MLA, AMPC and JBS representatives were invited to observe trials undertaken at Scott Dunedin.

Feedback received on performance and testing methods was positive, with JBS continuing to make arrangement for the equipment to be installed at their Brooklyn plant in January 2024 for further demonstrations.

Short Loin ID	Grade	Size	Weight	Cut from end?	Weight of Chine	Weight of Chine (meat removed)
#1	"Manu"	"1-Rib"	**4.900kg**	TAIL	**0.940kg**	**0.750kg**
#2	"Manu"	"1-Rib"	**5.810kg**	HEAD	**1.150kg**	**0.885kg**
#3	"Bull"	"1-Rib"	**7.380kg**	TAIL	**1.265kg**	**1.030kg**
#4	"Bull"	"1-Rib"	**7.565kg**	TAIL	**1.150kg**	**0.975kg**
#5	"C13"	"1-Rib"	**6.860kg**	HEAD	**1.420kg**	**1.170kg**
#6	"C13"	"1-Rib"	**6.970kg**	HEAD	**1.465kg**	**1.100kg**
#7	"Premium (O2)"	"1-Rib"	**7.185kg**	TAIL	**1.310kg**	**0.965kg**
#8	"Premium (O2)"	"1-Rib"	**7.225kg**	HEAD	**1.400kg**	**1.085kg**
#9	"Premium (O2)"	"1-Rib"	**6.895kg**	TAIL	**1.310kg**	**0.925kg**
#10	"Manu"	"1-Rib"	**4.980kg**	HEAD	**1.180kg**	**0.785kg**
#11	"Manu"	"1-Rib"	**4.260kg**	HEAD	**1.300kg**	**0.910kg**
#12	"Bull"	"1-Rib"	**7.925kg**	TAIL	**1.565kg**	**1.365kg**
#13	"Bull"	"1-Rib"	**7.380kg**	TAIL	**1.490kg**	**1.160kg**
#14	"Premium (O2)"	"1-Rib"	**6.755kg**	HEAD	**1.185kg**	**0.935kg**

Grades:
"Bull" – Bull
"Manu" – Manufacturing cow
"Premium (O2)" – Prime steer or heifer
"C13" – Prime cow, roughly the same size and fat cover as steer/heifer

*Figure 13 – SL9, chine bone still clamped,
showing bases of button bones, feather bones and transverse processes.*

Figure 14: SL9, chine cut plane on striploin, showing button bones split from transverse processes and feather bones.

Figure 15 – SL9 chine bone fleeced of tissue (viewed from cut plane)

4.7 Shipping, installation & set up for demonstrations.

4.7.1 Shipping

After receiving approval to ship to site, a 20ft container was packed and shipped to JBS Brooklyn on the 6th of January 2024.

Figure 16 – Shipping container delivered to Scott Dunedin, ready to pack equipment.

Figure 17 – Equipment being loaded onto export grade wooden pallets.

Figure 18 – Robot tied down to pallet and load points of container.

Figure 19 – 20ft container packed.

4.7.2 Installation

Mechanical installation of the demonstration equipment occurred over the non-production days of Saturday and Sunday the 24th and 25th of February 2024.

Figure 20 – Location of robot cell within JBS Brooklyn beef boning room marked out in yellow paint.

Figure 21 – Room preparation works: Meat rail above robot cell removed & belt conveyor cut back.

Figure 22 – Room preparation works: Electrical power supply and network connection point.

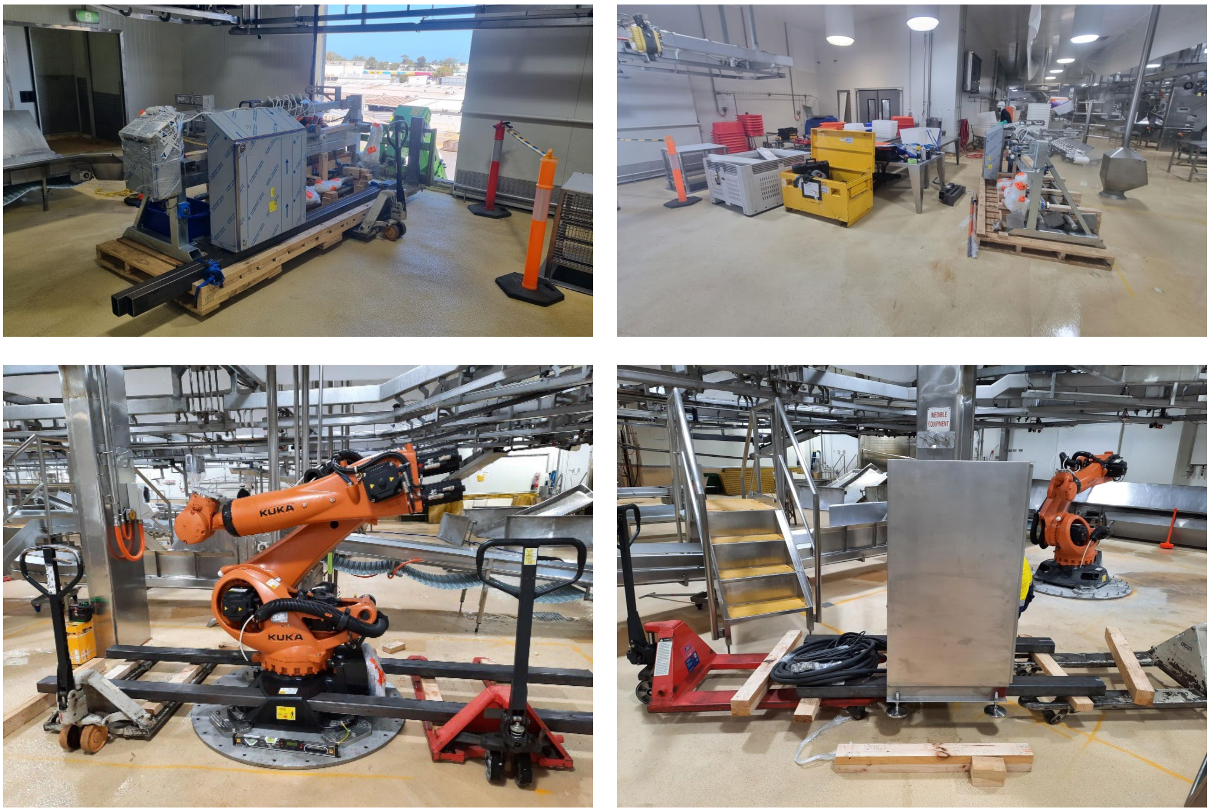

Figure 23 – Lift and position of equipment.

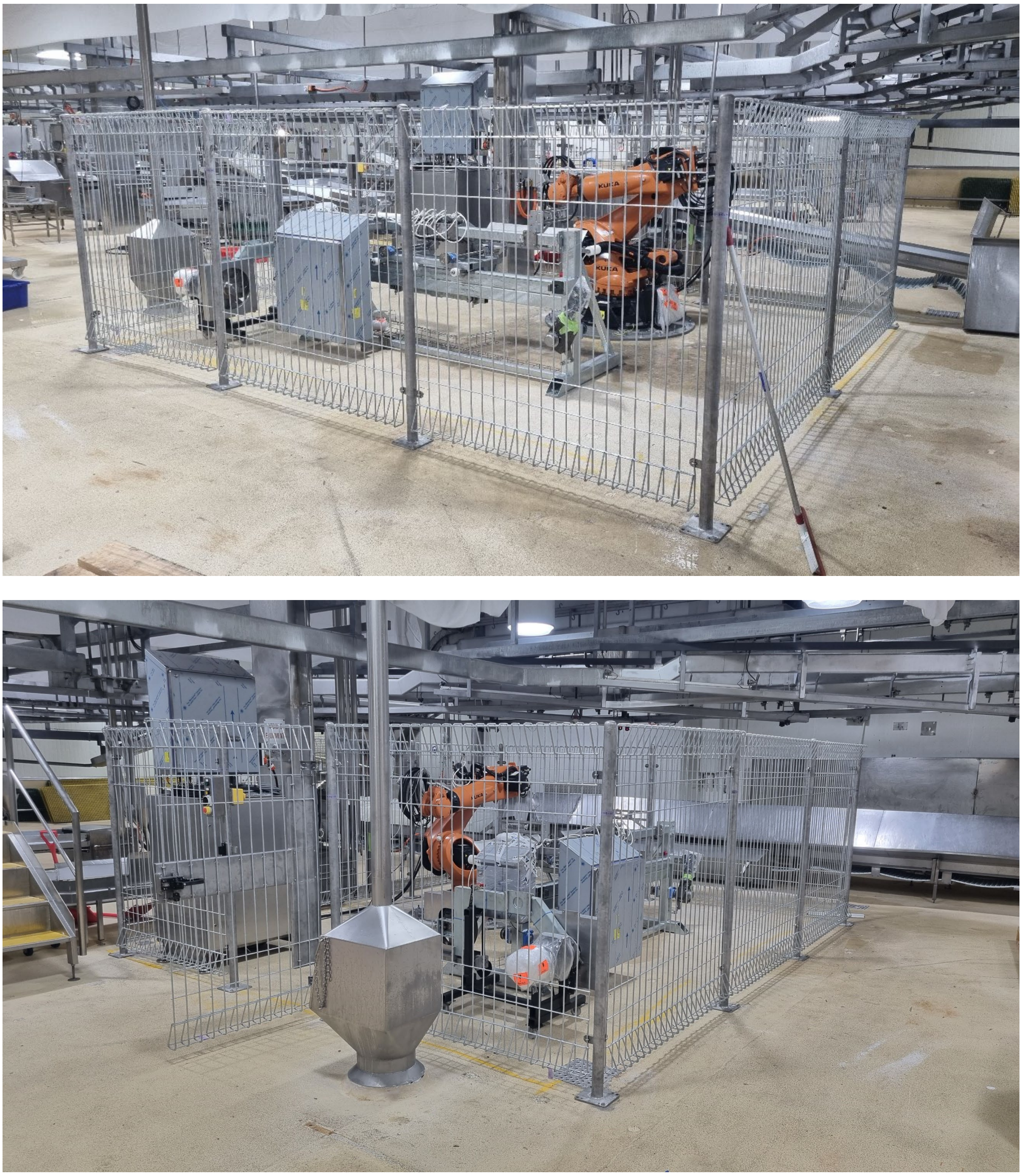

Figure 24 – Equipment in position anchored to floor, guarding erected. Ready for reticulation.

4.7.3 Setup for demonstration

Reticulation, wiring commissioning of the demonstration equipment occurred from the 27th of February 2023 to the 1st of March 2024.

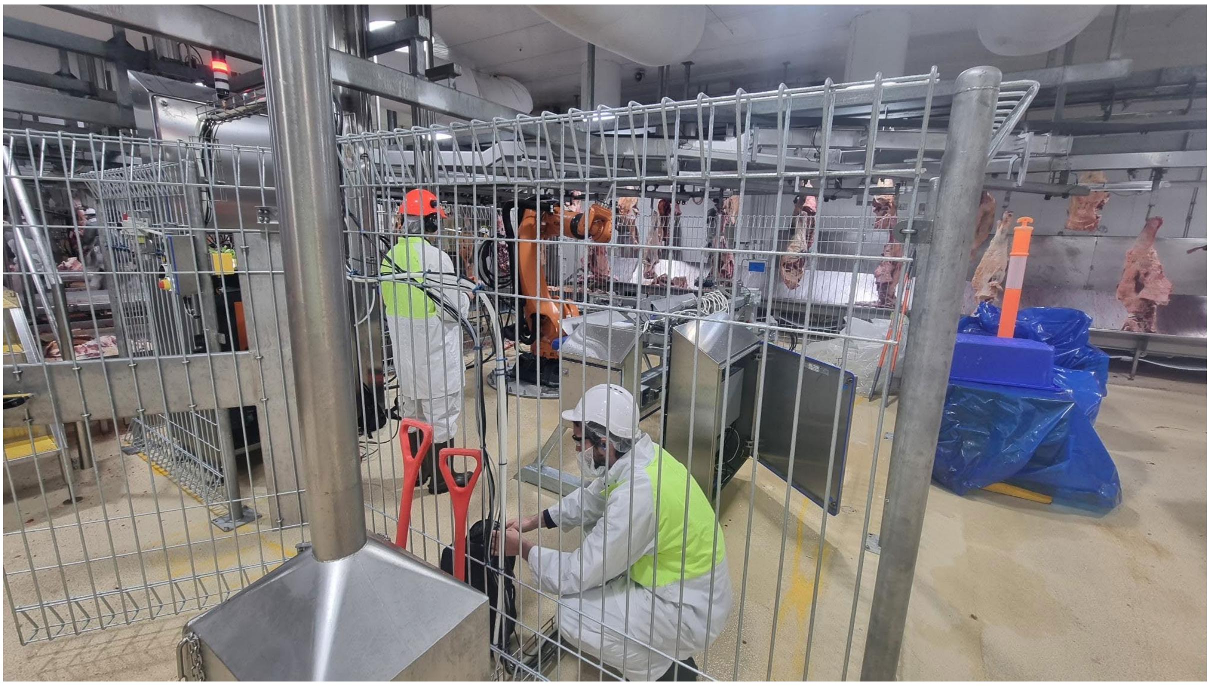

Figure 25 – Robot being re-mastered & vision system being commissioned.

Figure 26 – Robot with cover installed, ready to begin cutting trials.

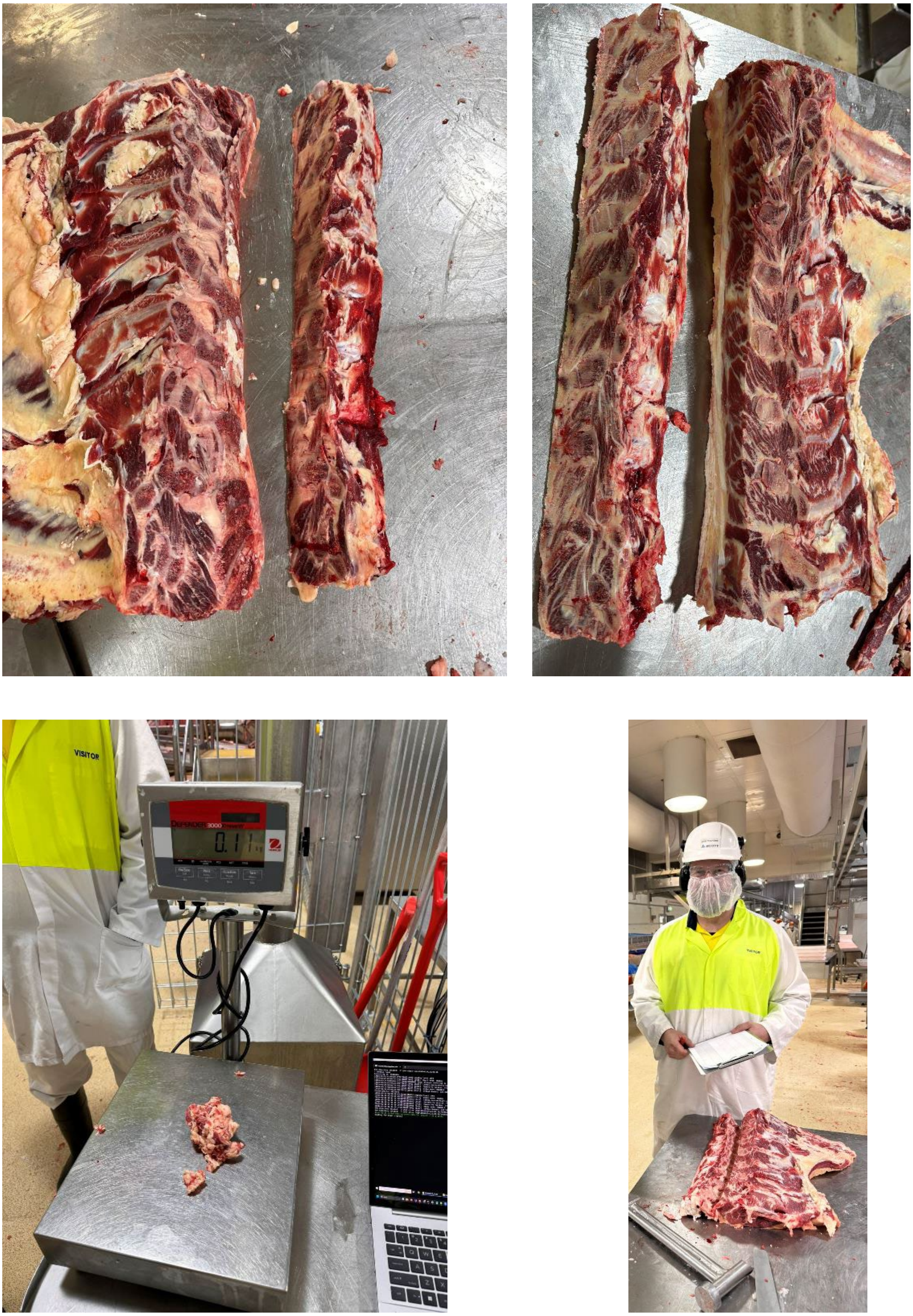

Figure 27 – First cuts and results. JBS head boner assisting with fleecing the chine bones of saleable meat.

4.7.4 Average Button Valley Depth Along Product – 0 Rib short loins

The data collected shows the measured normal distribution of the average button valley depth along manually cut product, and the same curve shifted so that -2σ, two standard deviations below the mean, lines up on the x-axis at -2mm.

This signifies that 2.5% of product manually cut would have an average button valley depth below -2mm.

-2mm has been selected as a limit of depth due to the remaining bridges usually being able to be broken readily by finger pressure. It is assumed that the loss of benefit when rework is required exceeds the yield benefit.

The data shows the measured normal distribution of the average button valley depth along robot using CNN cut product and the same data shifted so that -2σ, two standard deviations below the mean, lines up on the x-axis at -2mm.

This signifies that 2.5% of product manually cut would have an average button valley depth below -2mm.

-2mm has been selected as a limit of depth due to the remaining bridges usually being able to be broken readily by finger pressure. It is assumed that the loss of benefit when rework is required exceeds the yield benefit.

4.7.5 Average Button Valley Depth Along Product – 2 Rib short loins

The data shows the measured normal distribution of the average button valley depth along manually cut product and the same data shifted so that -2σ, two standard deviations below the mean, lines up on the x-axis at -2mm.

This signifies that 2.5% of product manually cut would have an average button valley depth below -2mm.

-2mm has been selected as a limit of depth due to the remaining bridges usually being able to be broken readily by finger pressure. It is assumed that the loss of benefit when rework is required exceeds the yield benefit.

The data shows the measured normal distribution of the average button valley depth along robot using CNN cut product, and the same data shifted so that -2σ, two standard deviations below the mean, lines up on the x-axis at -2mm.

This signifies that 2.5% of product manually cut would have an average button valley depth below -2mm.

-2mm has been selected as a limit of depth due to the remaining bridges usually being able to be broken readily by finger pressure. It is assumed that the loss of benefit when rework is required exceeds the yield benefit.

Figure 29 – Example of striploin product as cut by robot bandsaw.

Figure 30 – Example of striploin with chine bone as cut by robot bandsaw.

4.8 Demonstration in plant

On the 9th April 2024, representatives from MLA, AMPC and multiple JBS sites came together at JBS Brooklyn to review stage 1 progress, as presented by SCOTT, and provide input into the next steps.

Figure 31: Demonstration at processor.

Organisation	Participant	Role
AMPC	Stuart Shaw	Program Manager (Advanced Manufacturing)
	Jemma Harper	Innovation Manager
MLA	John McGuren	Project Manager
JBS	Sean Starling	Innovation Manager (Southern)
	Craig Miller	Brooklyn Plant Manager
	Sean May	Townsville Plant Manager
	Glen Kitching	Engineering (Northern)

	Mitchel Brereton	Riverina Beef City
	Luke Blackberry	Longford Plant Manager
SCOTT	Nick Stanford	Sales and Development Manager ANZ
	Andrew Thomson	Solutions Engineer – Meat Processing
	Steve Maunsell (remote)	Project Manager

Notes from demonstration meeting (specific to robotic loin chining):

- There are already many people boning beef that are skilled and focused on clean bones, automation will save labour rather than improve yield.
- The current installed R&D pilot chine cell is not used continuously because it does not perform as well as a person. It tends to be used for 0 rib loins rather than 2 rib loins.
- Brooklyn bones 100 bodies per hour. (200 sides per hour.) 4 saws are used to chine loins. (50 loins per hour / 400 loins per day.)
- Brooklyn can kill at 1250 per day / 156 per hour. Night shift boning processes at a lower rate than dayshift.
- A good operator on a good saw can get a blade to last for a whole day.
- The steering committee were keen to see cut accuracy improved to be at least as good as a person.
    - If the machine can chine loins as well as a person there is a labour saving based on a single person chining 50 loins per hour.
    - If the machine can chine loins better than a person there is also a yield improvement.
- Space is a concern at most plants. It was suggested that small manually loaded chining cells that incorporated a standard BladeStop™ saw to replace BladeStop saws used for chining.

5. Conclusion

5.1 Key findings

- Both factory and site demonstrations were well received by processor JBS.
- CNN vision analysis provided better accuracy than traditional vision analysis.
- When aligned normal distribution curves for cut depth error are compared, the automatically cut product mean is between 1.0mm to 1.4mm more than the mean of manually cut product at JBS Brooklyn.
- Using the current simple sensing means (cameras at each end), the mean of cut depth error is 5.3mm to 8.1mm more than the expected results from advanced sensing means (CT scanning).
- Learnings from bandsaw operators at site show that a curved cut path, rather than a straight cut path, is noticeably more accurate for products that have ribs attached.
- Unsatisfactory accuracy is being achieved using the current markers.
- Initially the bandsaw was run using a thinner blade but was unable to not last longer than 50-60 products. A standard blade, as used on BladeStop™ saw, proved to last significantly longer.

5.2 Benefit to industry

The current stage 1 module does not improve yield through cut accuracy when compared to the current manual cutting method. However, with further development to improve the accuracy, the following yield benefit could be realised.

Based upon an average 1mm cross section of meat left behind on the chine bone of 28.88g, and a value of $25/kg for strip loin meat, there is up to $2.82 for 0-rib products and up to $5.13 for 2-rib products of value not recovered per product (side).

A highly skilled bandsaw operator may earn up $110,000 AUD per year, while an unskilled labourer may earn up to $70,000AUD per year. Replacing 4 highly skilled operators with labourers would provide a labour saving of up to $160,000 AUD per year.

Assuming the next stage development machine can improve on a manual cut product by 1mm for 0-rib product and 2mm for 2-rib product, this would result in a yield benefit of:

- $0.722 AUD per 0-rib striploin*
- $1.444 AUD per 2-rib striploin*

JBS Brooklyn currently process 1600 sides a day, assuming the split between the two product sizes is 50/50, this equates to a gained value of $415,872AUD per year (based on 240 production days in the year).

Using the above assumed benefits, the value of equipment utilising a 2-year payback would equate to:

$991,744 AUD**

*	This benefit is plant and commercial solution dependant.
**	There may be further costs associated with equipment installation.

6. Future research and recommendations

SCOTT, with MLA & AMPC support, has installed a robotic chining system (stage 1) with end view vision system at JBS Brooklyn. The system has been commissioned, vision system tuned, trials done and preliminary demonstrations delivered. The results from stage 1 indicate less accuracy obtained than is typical from a manually cut product. Therefore, a stage 2 is proposed, to implement further sensing, enhance imitating the human operator, re-implement, train and trial.

Objectives:

- Upgrading the sensing means on the Brooklyn stage 1 test system.
- Obtain the error from the ideal cut path data for both the manual and robotic system and report.
- Given the measured improvement versus the manual operation, propose a path to a commercial system.

Table of figures